Precision Lightweight Mirrors for Suborbital Telescopes

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Precision Lightweight Mirrors for Suborbital Telescopes

Task Objective

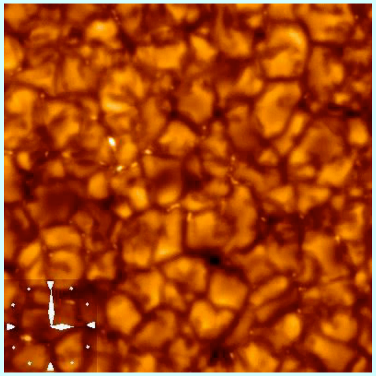
- Carry out in-house testing of a 50-cm parabolic mirror specified to be the best lightweight ultraviolet mirror ever made (in the light of day).
- Design and fabricate a flight-capable mount for this mirror and demonstrate that it could survive launch and support the mirror without significant distortion.
- Develop facilities and expertise necessary to space-qualify large-aperture, smooth, ultraprecise lightweight optics.
  - Lightweight: < 15 kg m^{-2}
  - FUV: < 200 nm
  - Smooth: < 1 nm microroughness
  - Ultraprecise: < 10 nm rms figure error

How We Got Here

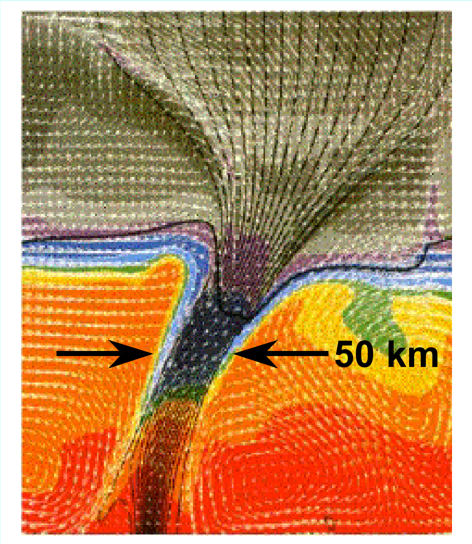
- Procured over a ~5-year period from Kodak (now ITT Space Systems)
- Intended as technology development for a solar EUV spectrograph
- Recast for nearer-term application as a UV imager with angular resolution < 0.2 arcsec (SHARPI)
- Parallel developments of primary (Schafer Corp.) and secondary (SSG/Tinsley) mirror architectures through SBIR collaborations
- In 2005, joined the PICTURE collaboration
- NASA Innovative Partnership Program (2006-7)

Solar High Angular Resolution Photometric Imager (SHARPI)

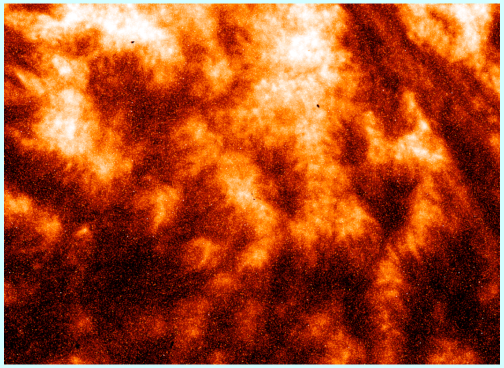
Studying the Sun on the scale of magnetic flux tubes and the photon mean free path in the photosphere has been a high-priority goal of solar physics for well over two decades. The highly structured and intermittent magnetic field in the solar atmosphere is the source of solar activity and its terrestrial effects.



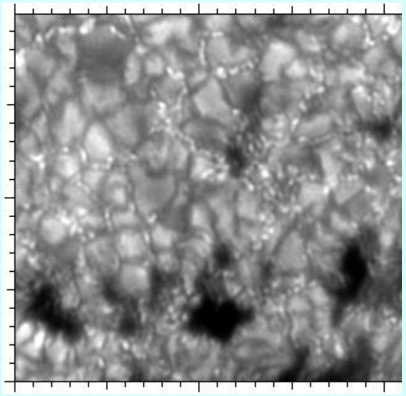
Hinode SOT



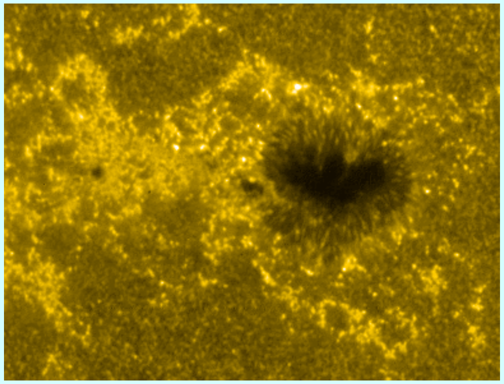
Flux Tube MHD model



VAULT sounding rocket (L_)



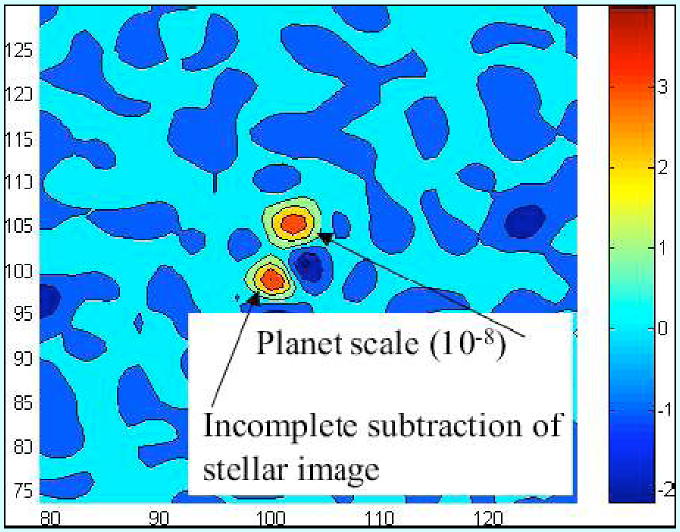
Swedish solar telescope

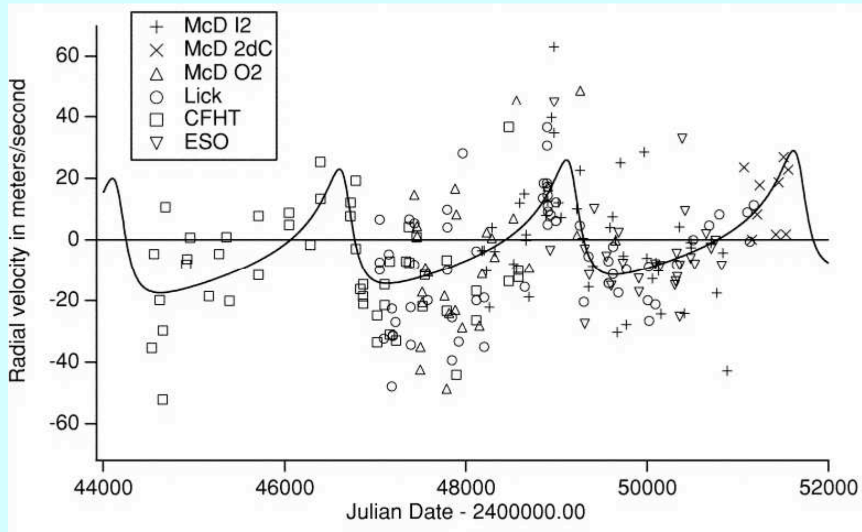


TRACE 160 nm continuum

PICTURE

Planetary Imaging Concept Testbed Using a Rocket Experiment *



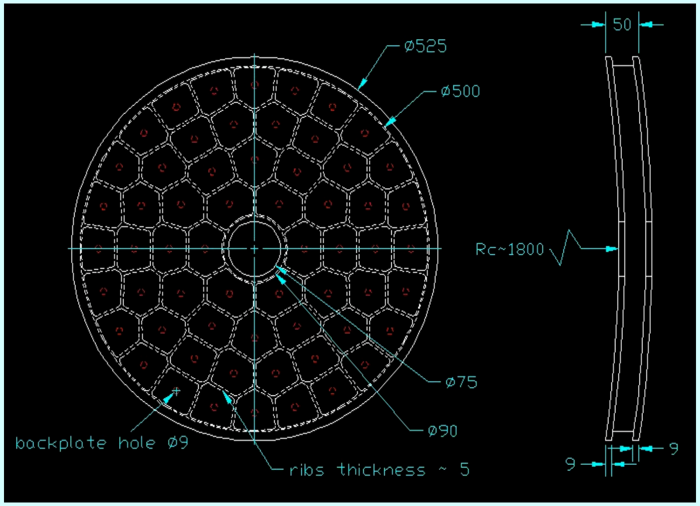


- **PICTURE is a 0.5-m telescope that fits in a sounding rocket.**
- PICTURE aims to obtain the first direct image of a planet around another star: _ Eri, which radial velocity measurements show to have a close Jovian-class planet.

* PI: S. Chakrabarti, Boston University. Co-I institutions: JPL, MIT, GSFC

The Mirror

Material	ULE
Construction	honeycomb with faceplate and backplate
Outer diameter	55.9 cm
Inner diameter	14.0 cm
Edge thickness	4.8 cm
Faceplate thickness	0.36 cm
Focal length	65 cm
Global surface figure	parabolic, < 6.3 nm rms
Microroughness	< 1 nm rms (spatial periods 1 μm _ 1 mm)
Midfrequency roughness	< 2.5 nm rms (spatial periods 1 _ 10 mm)
Mass	4.5 kg
Areal density	19.8 kg m^{-2}

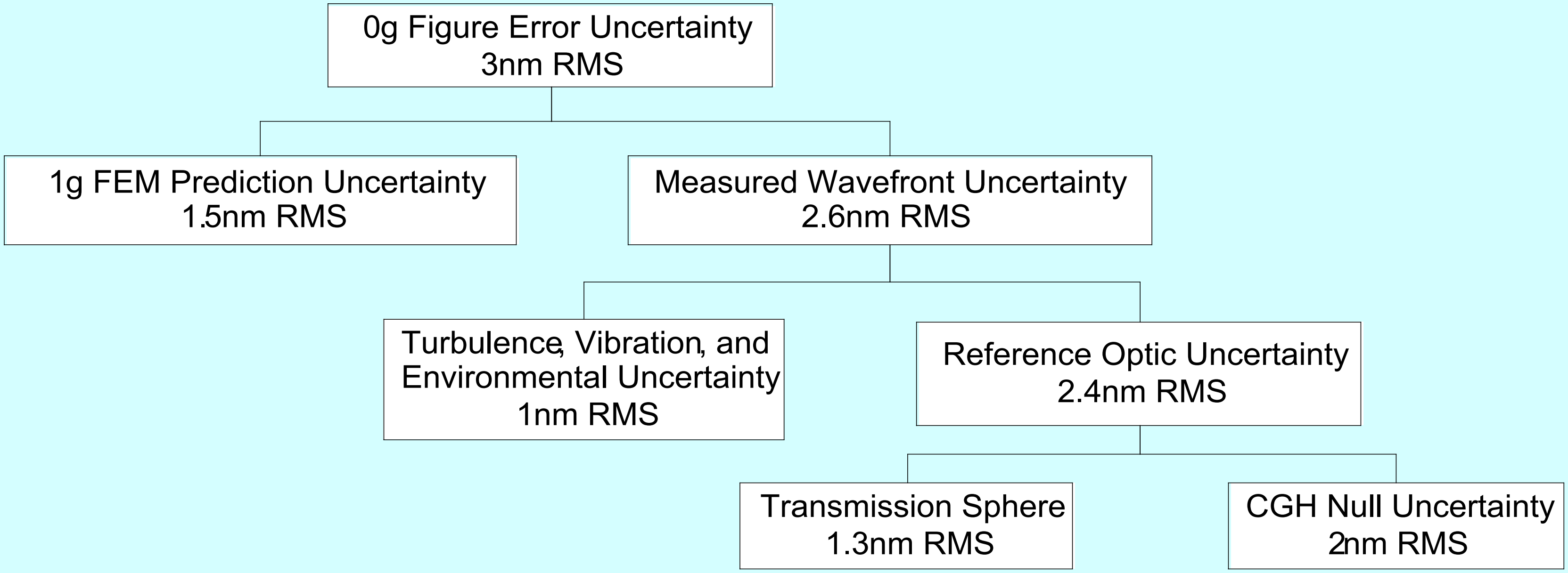


Steps to Flight (1)

Test Plan and Metrology Uncertainty Budget

Retrieve 0g figure error by subtracting systematic contributions.

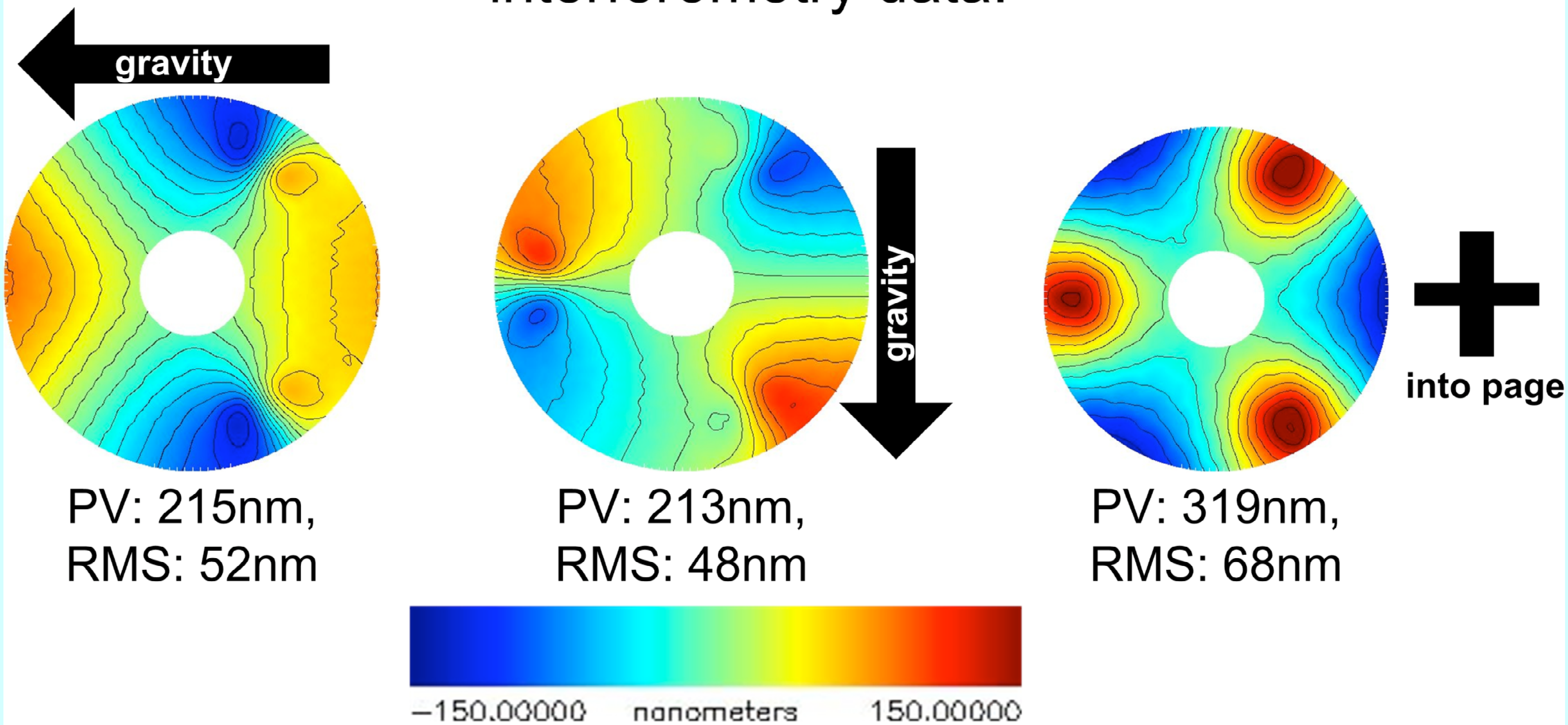
Total uncertainty in subtraction should not exceed 3nm RMS.



The Elephant in the Room

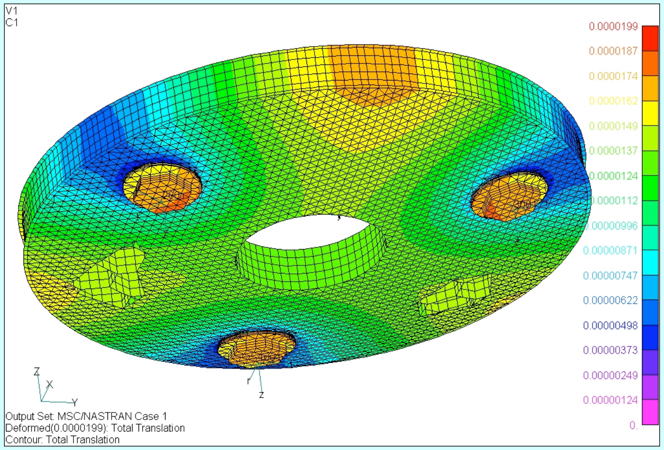
FEM 1g deflection predictions

Modeled sags need to be subtracted from interferometry data.

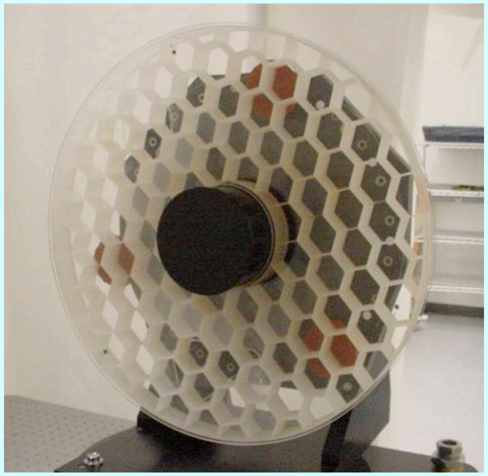


facing mirror, same clocking orientation
contour lines mark 20nm elevation increments

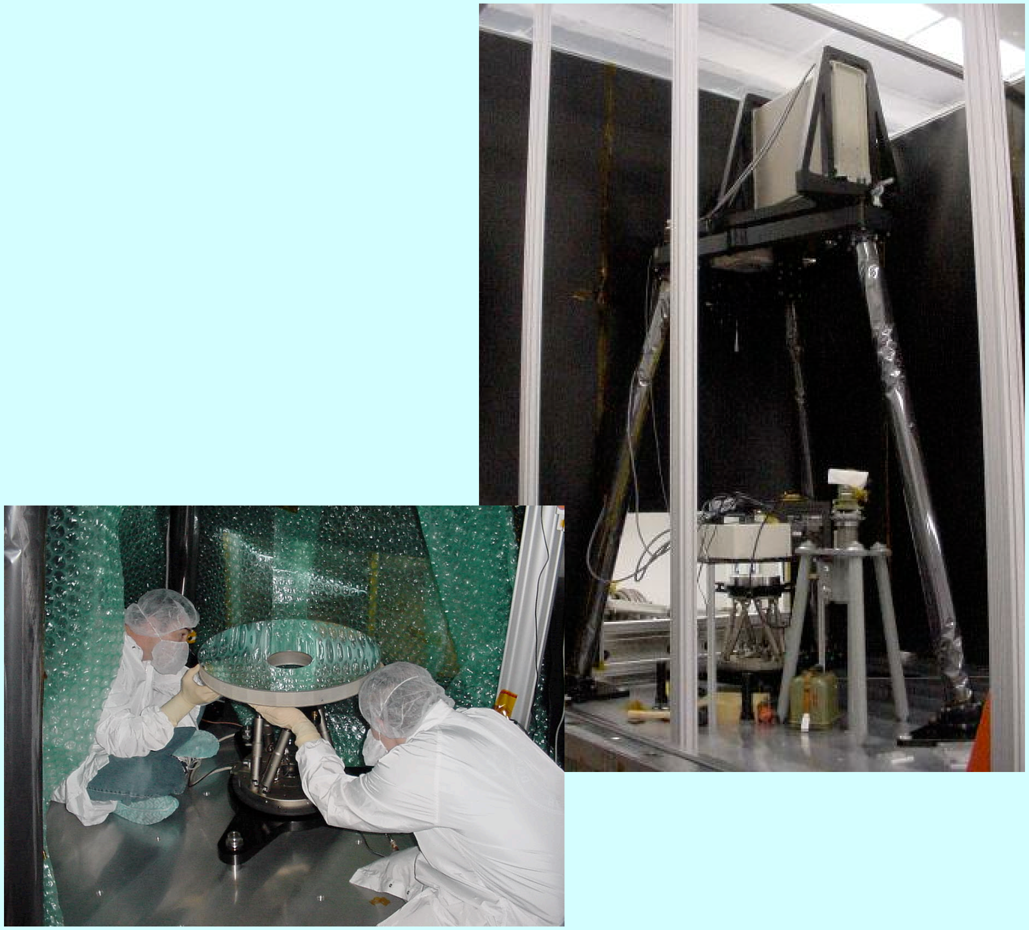
Steps to Flight (2)



Finite Element Modeling

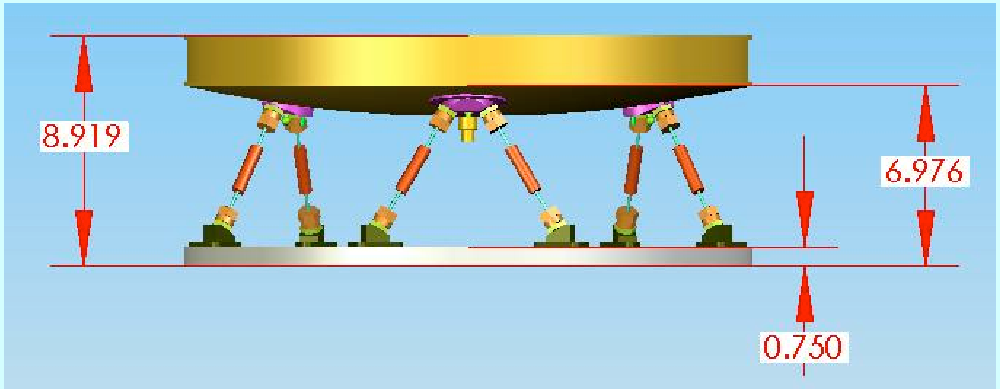


Horizontal Testing

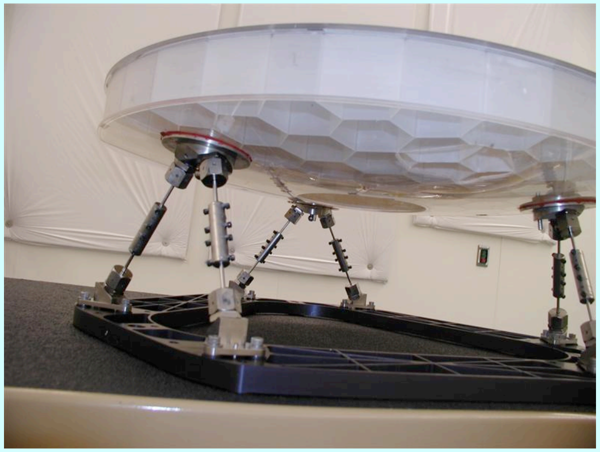


Vertical Testing of Unmounted Mirror

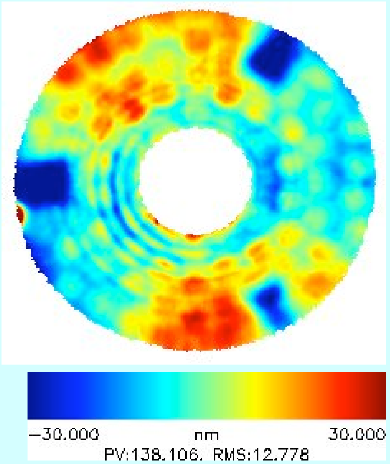
Steps to Flight (3)



Mount Design and Fabrication



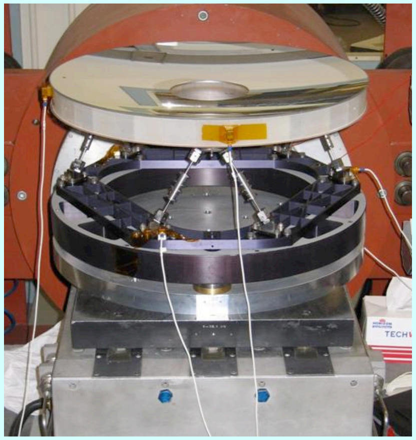
Mounting with Interferometric Monitoring



0g figure error as reduced from 4 rotational sequences

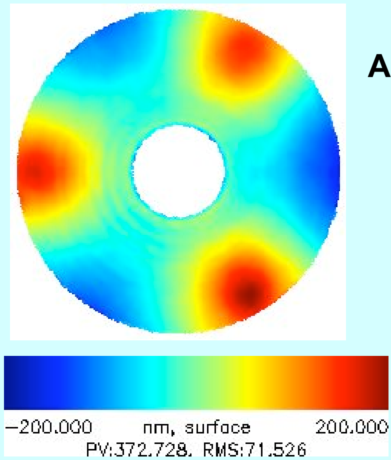
Total RMS uncertainty: ±5.1nm RMS

More Horizontal Testing → ∞ Analysis → Result



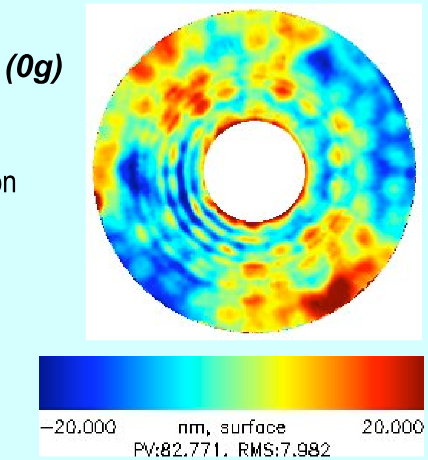
Coated and mounted mirror in vibration testing at Wallops Flight Facility

Figure Metrology & Analysis



Average Figure Measurement *(1g)*
RMS:71.5nm+/-5.6nm
Corrections applied:
reference wavefront, image distortion

Average Figure Measurement *(0g)*
RMS:8.0nm+/-5.6nm
Corrections applied:
NASTRAN predicted 1g deformation



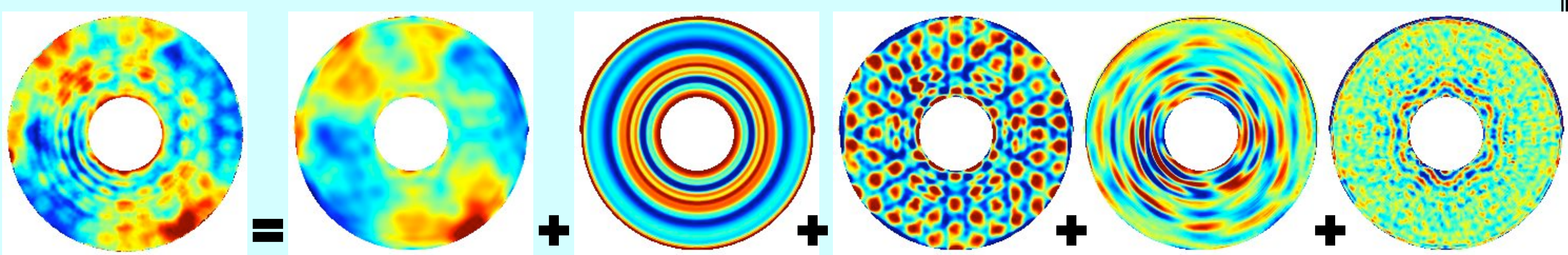
Measuring 0g Mirror Figure

Measuring precise lightweight mirrors in the presence of large gravity deformations

scale magnification: x10

Error Analysis & Decomposition

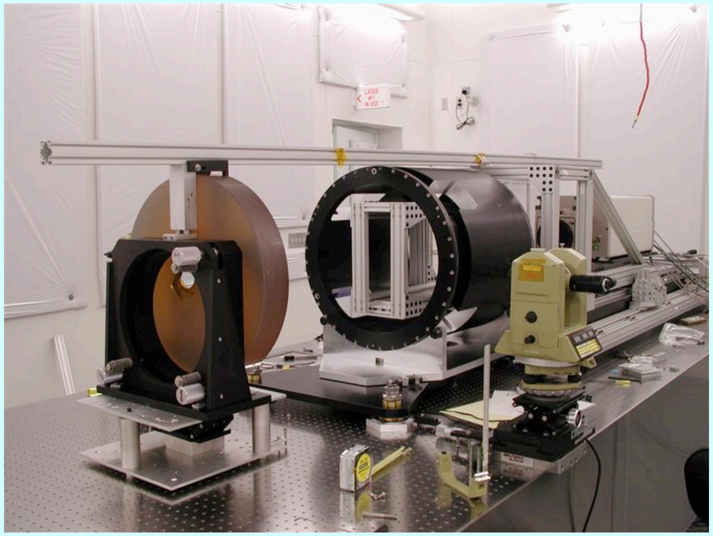
Understanding the magnitude and character of the mirror figure error and our measurement uncertainty.



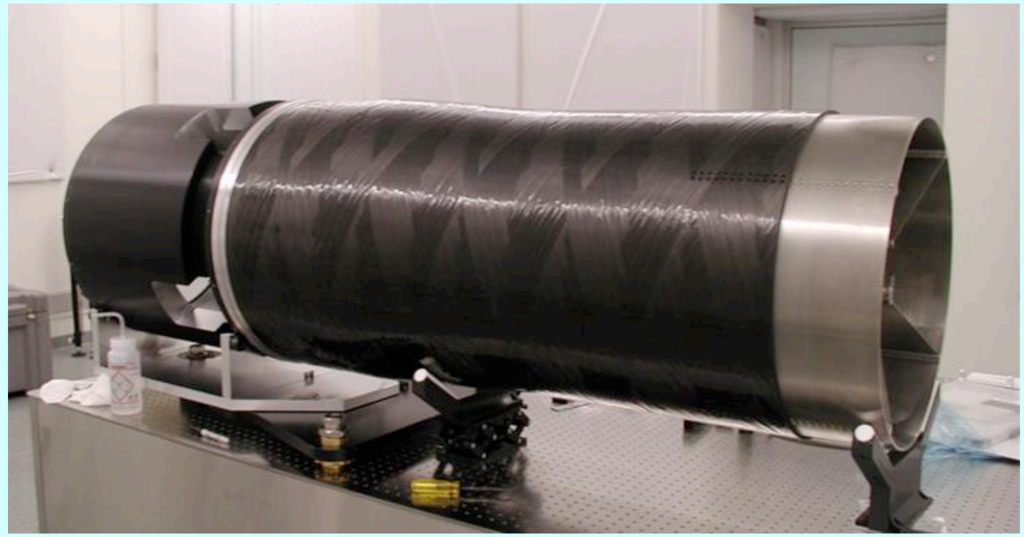
Total 0g Error RMS:8.0nm+/-5.5nm = **Asymmetric Figure Error** RMS:6.9nm+/-5.5nm + **Symmetric Radial Error** RMS:3.1nm+/-0.4nm + **"Quilting" Error** RMS:2.7nm+/-0.3nm + **Semi-Symmetric Error** RMS:2.1nm+/-0.5nm + **Residual** RMS:1.7nm+/-0.5nm

scale magnification: x5

Steps to Flight (4)



Lots of GSE



+ BU and GSFC flight articles

→ Aligned Telescope

→ Integration with JPL nuller and MIT camera

The Future (1)

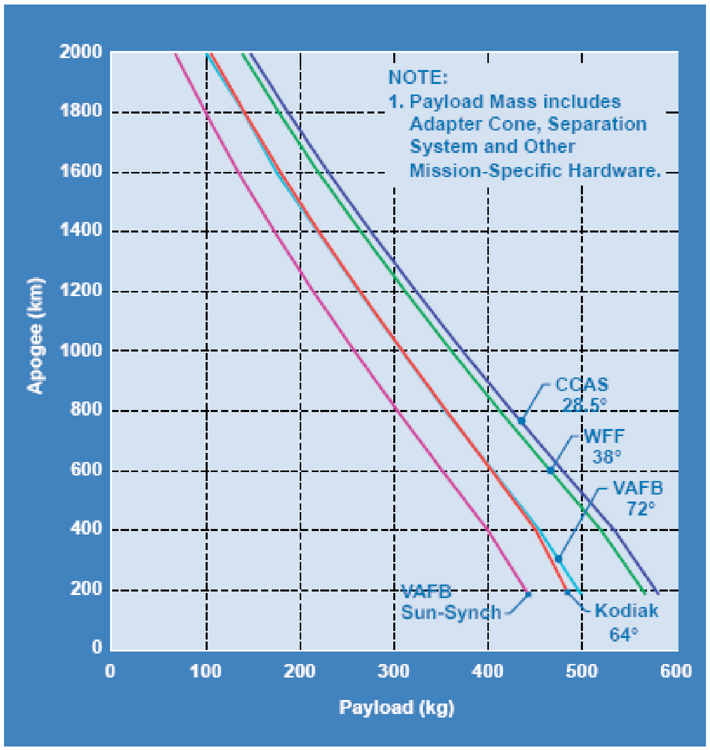
Lightweight Cryostable Low-Cost Mirrors for the Next Generation of Space Telescopes

- NASA Innovative Partnership Program
- Co-PI (NASA) – David Content
- Co-PI (ITT Space Systems) – David Strafford
- Other participants
  - GSFC
    - Doug Rabin – Science
    - Dominic Benford – Science
    - Sandra Irish – Stress Analysis
    - Brian Ross – Test lead
    - Scott Antonille – Optical testing
  - MSFC
    - Ron Eng – Cryogenic Optical Testing
  - ITT
    - Rob Egerman – Mechanical Design & Analysis

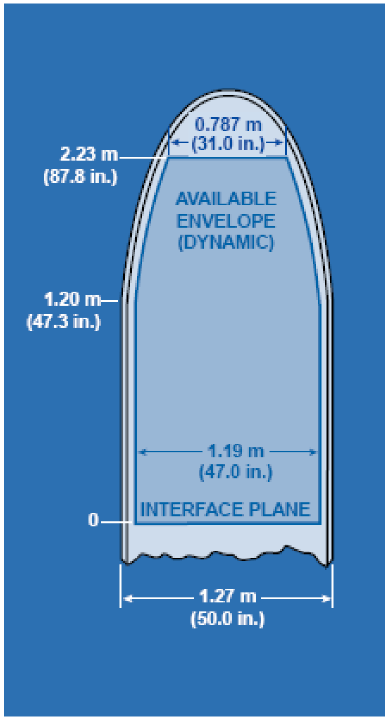
“Corrugated” plano 0.5-m mirror, 1.6 kg

Cartoon of mounted mirror assembly

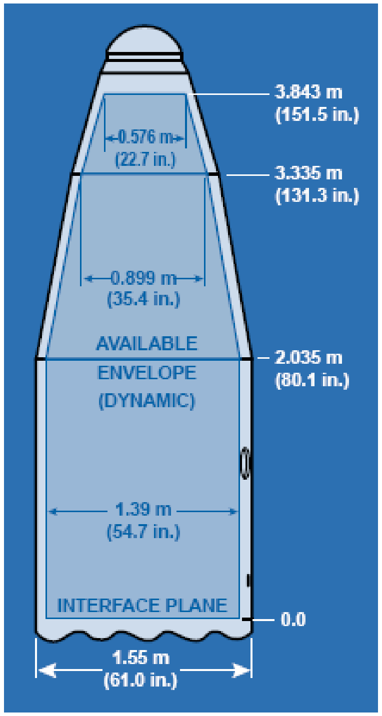
The Future? (2)
Minotaur



Performance to Orbit Is Flight-Verified and Best in Class



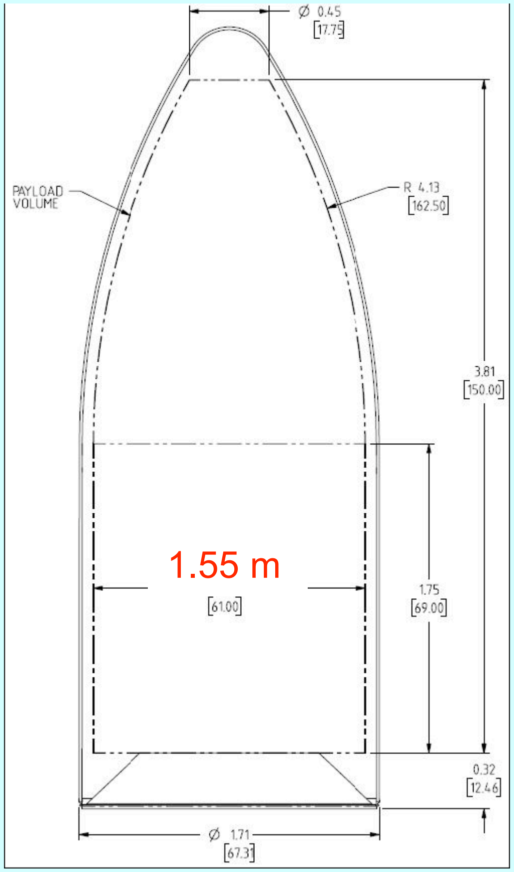
Standard 1.27 m (50 in.) Fairing Envelope



Optional 1.55 m (61 in.) Fairing Envelope

Minotaur orbital performance and faring envelopes

The Future? (3)
Falcon



Falcon 1e standard fairing and dynamic envelope*, meters [inches]